Spin-on-glass smoothing of diamond-turned fly-eye illumination mirrors

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MOTIVATION

- Fly-eye mirrors serve as effective homogenizing elements in illumination systems
- Diamond turning technology enables rapid low-cost fabrication of complex optics such as fly-eye mirrors
  - Illuminator optic figure specs readily achieved, however, surface finish inadequate for EUV optics
- Post-fabrication smoothing of diamond-turned optics is required to use these optics in the EUV

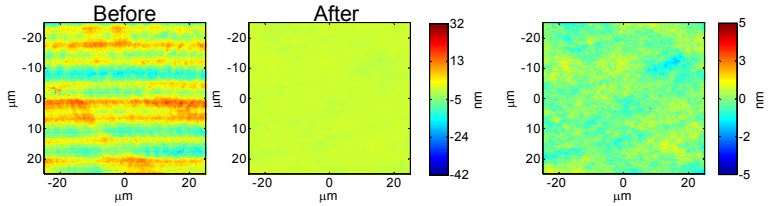
PROCESS OVERVIEW

- Start with commercial diamond-turned part
- Coat with 100-nm layer of HSQ spin-on-glass
- Cure in UV-ozone oven
- Repeat coat and cure steps 5 times
- Coat with conventional EUV multilayer
- Thinner HSQ process selected due to concerns of loss of fidelity on shallow fly-eye lenslets

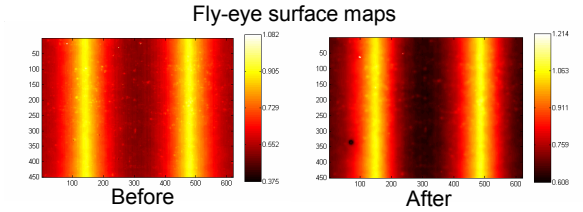
RESULTS

- Roughness reduced from 6.6 nm to 0.45 nm
- Figure preserved
  - Final slope error <40 μrad (spec = 1 mrad)
- 64% reflectivity, 0.57-nm bandwidth achieved
- Components successfully integrated into upgraded MET illuminator
  - ~3x increase in uniform field size

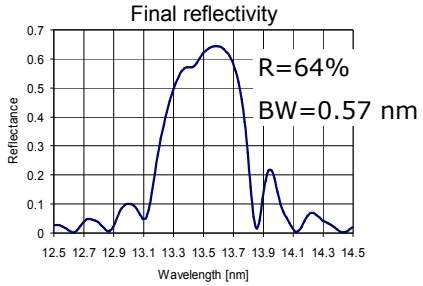
DATA



- AFM images before and after smoothing with 500-nm of HSQ. RMS roughness reduced from 6.6 nm to 0.45 nm
- After AFM image rescaled

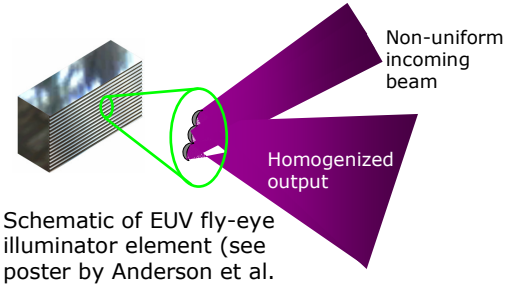


- Micromap images of a single lenslet before and after smoothing with 500-nm of HSQ

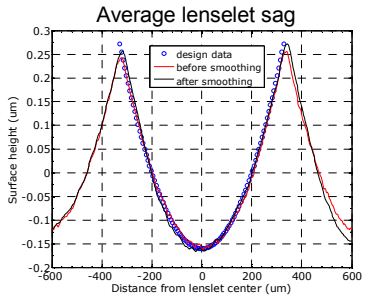


BACKGROUND

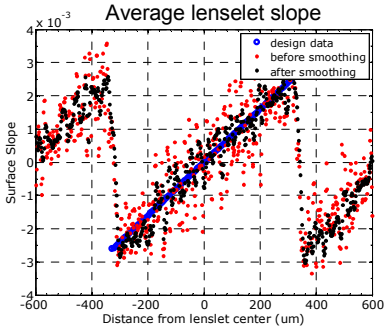
- **Spin-on coatings have been used in the past to smooth simple diamond-turned optics**
  - Polyimid ~3-μm thick
    - Soufli et al, Proc. SPIE **5193**, 98 (2004)
  - HSQ (spin-on-glass) ~100-500 nm thick
    - Salmassi et al, Appl. Opt. **45**, 2404 (2006)
- **Fly-eye comprised of several small lenslets**
  - Used as field integrating device for improved illumination uniformity
  - In our application each lenslet is small and shallow cylinder (~500-μm wide, 1-μm deep)



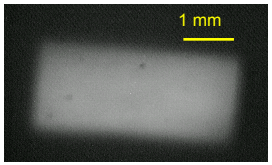
- Schematic of EUV fly-eye illuminator element (see poster by Anderson et al. for details)



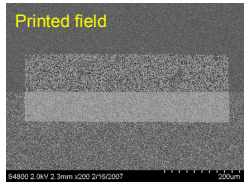
- Comparison of average sag across single lenslet before and after smoothing and design.
- Good fidelity observed both from the diamond-turning process and smoothing procedure



- Single lenslet average slope
- Effective smoothing obtained with low-frequency slope error compared to design < 40 μrad



- Final illumination pattern at mask



- Example printed full-field pattern on wafer

SUMMARY

- Spin-on-glass smoothing effective for highly asymmetric fly-eye parts
- Roughness reduced from 6.6 nm to 0.45 nm
- Shallow 1-μm deep design features accurately preserved
- 64% EUV reflectivity achieved from diamond-turned fly-eye element

ACKNOWLEDGEMENTS

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